

## REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-01881a. REPORT SECURITY CLASSIFICATION  
Unclassified

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

3. DISTRIBUTION / AVAILABILITY OF REPORT  
Approval for public release.  
Distribution unlimited.

AD-A226 790

5. MONITORING ORGANIZATION REPORT NUMBER(S)  
AFOSR-TR- 90 09146a. NAME OF PERFORMING ORGANIZATION  
Cornell University6b. OFFICE SYMBOL  
(If applicable)7a. NAME OF MONITORING ORGANIZATION  
Air Force Office of Scientific Research6c. ADDRESS (City, State, and ZIP Code)  
119 Phillips Hall  
Ithaca, NY 14853-54017b. ADDRESS (City, State, and ZIP Code)  
Building 410, Bolling Air Force Base  
Washington, DC 20332-64488a. NAME OF FUNDING / SPONSORING  
ORGANIZATION8b. OFFICE SYMBOL  
(If applicable)9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  
F49620-87-C-0044

8c. ADDRESS (City, State, and ZIP Code)

10. SOURCE OF FUNDING NUMBERS

PROGRAM  
ELEMENT NO.PROJECT  
NO.TASK  
NO.WORK UNIT  
ACCESSION NO.

11. TITLE (Include Security Classification)

Ultra High Speed Compound Semiconductors and Real Time Signal Processing

12. PERSONAL AUTHOR(S)

J. Peter Krusius

13a. TYPE OF REPORT  
Final Report13b. TIME COVERED  
FROM 5/1/88 TO 4/30/9014. DATE OF REPORT (Year, Month, Day)  
90/06/3015. PAGE COUNT  
16

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD GROUP SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Compound semiconductor, organometallic vapor phase epitaxy,  
femtosecond laser probing, Monte Carlo simulation, VLSI,  
fault tolerance, computer architecture

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report is the final report on research conducted under the auspices of the Joint Services Electronics Program at Cornell University. The research is grouped under two themes: (a) ultra high speed compound semiconductors, and (b) real time signal processing. Results on OMVPE materials growth, femtosecond laser probing of hot carriers, and ensemble Monte Carlo simulations are reported on under the first theme. Accomplishments on VLSI algorithms, fault tolerant architectures, and architectures with multiple functional units for signal processing are given under the second theme.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT

☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS21. ABSTRACT SECURITY CLASSIFICATION  
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL

22b. TELEPHONE (Include Area Code)

22c. OFFICE SYMBOL

AEOSR-TR- 90 09 14

TWO YEAR FINAL REPORT

ULTRA HIGH SPEED COMPOUND SEMICONDUCTORS  
AND  
REAL TIME SIGNAL PROCESSING

MAY 1, 1988 - APRIL 30, 1990

CONTRACT #F49620-87-C-0044



Accession For	
NTIS	CRA&I
DTIC	TAB
Unannounced	
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and/or Special
A-1	

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## DIRECTOR'S OVERVIEW

This document is the final report of the current two year Cornell Joint Services Electronics Program for the period from May 1, 1988 to April 30, 1990. The Cornell program was broadened from an exclusive focus on compound semiconductor materials and devices into a two theme approach at the beginning of this two year period. One of these themes continued the compound semiconductor research concentrating on more fundamental phenomena, femtosecond transport and optical phenomena in heterostructures, while the other theme added research in a new area, real time digital signal processing, to the program. The new objectives brought four new faculty (C. Pollock, G. Bilardi, F. Luk and H. Torng) to a total of seven principal investigators now participating in the program. During this two year period, all investigators have actively published and graduated one or more PhD students. The total number of PhD, MS, and Master of Engineering degrees awarded is 85, 11, 2, 1, respectively. 85 publications are listed in the individual tasks.

A major optoelectronics proposal was prepared to DARPA with Prof. C. Tang of Cornell University, one of the JSEP task leaders, as the principal investigator largely leveraging research interactions and expertise of past and current JSEP research at Cornell. The proposal titled "National Optoelectronic Materials Center" involved a team of universities (Cornell University and University of California Santa Barbara (UCSB) as the main institutions with contributions from Rensselaer Polytechnique Institute and Syracuse University). The Cornell/UCSB team was awarded about \$6M for a two year period. Contract negotiations between DARPA and the Cornell/UCSB team are now in the final stages and research is expected to commence before the end of the current federal fiscal year. At the time of this writing it appears that research proposed by all other JSEP task investigators of the compound semiconductor theme (R. Shealy, R. Pollock, and J. P. Krusius) will receive funding in addition to C. Tang under the DARPA optoelectronics program.

Efforts to establish the new compound semiconductor growth facility at Cornell have continued to be a collaborative issue for the JSEP faculty during the current program period. The new facility is expected to require continued attention well into future years of the program. It also serves as one of the cornerstones to the DARPA program. The existing organometallic vapor phase epitaxy (OMVPE) operation on the fourth floor of Phillips Hall had become substandard because of ever tightening hazard gas safety regulations. The new growth laboratory, a shared facility operated under the technical direction of R. Shealy, JSEP task leader, and an oversight committee consisting of users and administration, is being established in an existing building off-campus. The facility will comply with the most stringent hazard gas safety regulations in the country ("California code"). Construction of this new facility in an existing building calls for the installation of three independent OMVPE systems to be used for specialized growth tasks. One of these reactors will be the rebuilt reactor moved from Phillips Hall, the second a fully operational reactor donated by General Electric Company, and the third a reactor currently under construction.

Much of the effort in R. Shealy's JSEP task has been devoted to the establishment of this new OMVPE facility, which will provide truly unique capabilities for compound semiconductor heterostructure growth. Compound semiconductor JSEP faculty in addition to R. Shealy have contributed to the planning, fund raising, and extensive discussions with university administration because of the importance of this facility to JSEP and related research. The valuable and extensive experience acquired during the planning and construction of this facility will be made available to any interested DoD laboratory on request. At the time of this writing OMVPE reactors have been placed into the facility. Specialty gas delivery and exhaust systems are being connected to the reactors.

The three task investigators in the present program contributing to the real time signal processing theme, G. Bilardi, F. Luk and H. Torng, have held regular meetings, identified overlapping research areas, and started to define unifying research issues. Significant results have been accomplished by this group in the two years of the JSEP program.

## OMVPE GROWTH OF III-V ALLOYS AND STRUCTURES FOR NEW HIGH SPEED ELECTRON DEVICES

TASK #: 1

TASK PRINCIPAL INVESTIGATOR: J. Richard Shealy  
(607) 255-4657

### DEGREES AWARDED:

1. D. P. Bour  
Ph.D., January 1988  
"Organometallic Vapor Phase Epitaxial Growth and Characterization of AlGaInP for Visible Emitters"
2. M. Lestina  
M.S., May 1988  
"A Low Thermally Resistive Process for the CW Operation of Laser Diodes"

### ISEP PUBLICATIONS:

1. "Investigation by Raman Scattering of the Properties of III-V Compound Semiconductors at High Temperature," J. R. Shealy and G. W. Wicks, *Applied Physics Letters*, 50 (17) 1173-1175 (April 1987).
2. "Ga<sub>0.5</sub>In<sub>0.5</sub>P/GaAs Interfaces by Organometallic Vapor Phase Epitaxy," D. P. Bour, J. R. Shealy and S. McKernan, *Journal of Applied Physics*, 63 (4) 1241-1243 (February 1988).
3. "TEM Studies of Ordering in MOCVD Grown GaInP on GaAs," S. McKernan, B. C. DeCooman, C. B. Carter, D. P. Bour, and J. R. Shealy, *Proceedings of Materials Research Symposium*, 104, 637-640 (1988).
4. "Optical Investigation of Organometallic Vapor Phase Epitaxially Grown Al<sub>x</sub>Ga<sub>1-x</sub>P," D. P. Bour, J. R. Shealy, A. Ksendzov, and F. Pollak, *Journal of Applied Physics*, 64 (11) 6456-6459 (1988).
5. "Direct Observation of Ordering in (GaIn)P," S. McKernan, B. C. DeCooman, C. B. Carter, D. P. Bour, and J. R. Shealy, *Journal of Materials Research*, 3 (3) 406-409 (May 1988).
6. "Organometallic Vapor Phase Epitaxial Growth of (Al<sub>x</sub>Ga<sub>1-x</sub>)<sub>0.5</sub>In<sub>0.5</sub>P and Its Heterostructures," D. P. Bour and J. R. Shealy, *IEEE Journal of Quantum Electronics*, 24 (9) 1856-1863 (September 1988).

7. "Disordering, Intermixing, and Thermal Stability of GaInP/AlInP Superlattices and Alloys," S. O'Brien, D. P. Bour, and J. R. Shealy, *Applied Physics Letters*, 53 (19) 1859-1861 (November 7, 1988).
8. "The Characterization of Misfit Dislocations at {100} Heterojunctions in III-V Compound Semiconductors," B. C. DeCooman, C. B. Carter, K. T. Chan, and J. R. Shealy, *Journal of Act. Metall.*, 37 (10) 2779-2793 (1989).
9. "Plasmon-LO Phonon Interaction in n-type  $(\text{Al}_{0.3}\text{Ga}_{0.3}\text{As})_n(\text{In}_{0.3}\text{Ga}_{0.3}\text{As})_m$  Short Period Strained Layer Superlattices," Ostergaard, O. Leistiko, X. Song, J. R. Shealy, W. J. Schaff, L. F. Eastman and K. Yamasaki, submitted to *Journal of Applied Physics* (February 1990).
10. "Effects of Rapid Thermal Annealing and  $\text{SiO}_2$  Encapsulation on GaInAs/AlInAs Heterostructures," S. O'Brien, J. R. Shealy, D. P. Bour, L. Elbaum and J. Y. Chi, *Applied Physics Letters*, 56 (14) 1365-1367 (April 1990).
11. "Characterization of GaAs/AlGaAs Graded-Index Separate Confinement Heterostructure Lasers by Raman Scattering," J. Bradshaw and J. R. Shealy, presented at 1990 Conference on Lasers and Electro-Optics International Quantum Electronics Conference, Anaheim, CA, May 21-25, 1990.
12. "Characterization of GaAs/AlGaAs Graded Index-Separate Confinement Heterostructure Lasers by Raman Scattering," J. Bradshaw and J. R. Shealy, *Journal of Applied Physics*, 68 (1) 358-360 (1 July 1990).

## FEMTOSECOND LASER STUDIES OF ULTRAFAST PROCESSES IN COMPOUND SEMICONDUCTORS

TASK #: 2

TASK PRINCIPAL INVESTIGATOR: C. L. Tang  
(607) 255-5120

### DEGREES AWARDED:

1. F. W. Wise  
Ph.D., August 1989  
"Femtosecond Studies of Hot-Electron Relaxation in Semiconductors"
2. D. Edelstein  
Ph.D., October 1989  
"New Sources and Techniques for Ultrafast Laser Spectroscopy"

### ISEP PUBLICATIONS:

1. "Materials for Nonlinear Optics," C. L. Tang, Invited, *Proceedings IUPAC Chemrawn VI*, Tokyo, Japan (May 17-22, 1987).
2. "Polarization Switching in Single-Frequency External-Cavity Semiconductor Lasers," T. Fujita, A. Schremer, and C. L. Tang, *Elec. Letters*, 23, 803-804 (July 1987).
3. "Picosecond Relaxation of Hot-Carrier Distributions in GaAs/GaAsP Strained-Layer Superlattices," D. C. Edelstein, A. J. Nozik, and C. L. Tang, *Applied Physics Letters*, 51 (1) 48-50 (July 1987).
4. "Application of Linear Prediction Least-Squares Fitting to Time-Resolved Optical Spectroscopy," F. W. Wise, R. J. Rosker, G. L. Millhauser, and C. L. Tang, *Journal of Quantum Electronics*, QE-23 (7) 1116-1121 (July 1987).
5. "Femtosecond Relaxation Dynamics of Nonequilibrium Carriers in GaAs and Related Compounds," C. L. Tang, F. W. Wise, and I. A. Walmsley, *Proceedings of Fifth International Conference on Hot Carriers in Semiconductors*, Boston, MA (July 20-24, 1987); *Solid State Elec.*, 31 (3/4) 439-442 (1988).
6. "Experimental Determination of Hot-Carrier Scattering Processes in  $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ," F. W. Wise, I. A. Walmsley, and C. L. Tang, *Applied Physics Letters*, 51 (8) 605-607 (August 1987).

7. "Ensemble Monte Carlo Simulations of Femtosecond Energy Relaxation of Photoexcited Electrons in Bulk GaAs," D. Bailey C. Stanton, M. Artaki, K. Hess, F. Wise, and C. L. Tang, *Proceedings of Fifth International Conference on Hot Carriers in Semiconductors*, Boston, MA (July 20-24, 1987).
8. "Polarization Bistability in External-Cavity Semiconductor Lasers," T. Fujita, A. Schremer, and C. L. Tang, *Applied Physics Letters*, 51, 392-394 (August 1987).
9. "Bistability in Two-Mode Semiconductor Lasers via Gain Saturation," C. L. Tang, A. Schremer, and T. Fujita, *Applied Physics Letters*, 51, 1392-1394 (November 1987).
10. "Birefringence-Induced Polarization Counter-Rotation in a Semiconductor Laser," T. Fujita, A. Schremer, and C. L. Tang, *Applied Physics Letters*, 51, 1487-1489 (November 1987).
11. "Semiconductor Laser Diode Logic Gate Suitable for Monolithic Integration," W. J. Grande and C. L. Tang, *Applied Physics Letters*, 51, 1780 (November 1987).
12. "Femtosecond Laser Studies of Ultrafast Processes in Semiconductors and Large Molecules," C. L. Tang, F. W. Wise, and I. Walmsley, Invited, *Special Issue on Femtosecond Lasers and Ultrashort Phenomena, Revue de Physique Applique*, 22, 1695-1703 (December 1987).
13. "Single-Step Multi-Level Etching Technique for Monolithic Integrated Optics," W. J. Grande, W. D. Braddock, J. R. Shealy, and C. L. Tang, *Applied Physics Letters*, 51 (26) (December 1987).
14. "Instability Threshold Resonances in Directly Modulated External-Cavity Semiconductor Lasers," A. Schremer, T. Fujita, C. F. Lin, and C. L. Tang, *Applied Physics Letters*, 52, 263-265 (January 1988).
15. "Simultaneous Formation of Solitons and Dispersive Waves in a Femtosecond Ring Dye Laser," F. W. Wise, I. A. Walmsley, and C. L. Tang, *Optics Letters*, 13, 129-131 (February 1988).
16. "Measurement of Ultrashort Optical Pulses with Barium Meta-Borate," K. Cheng, W. Bosenberg, F. Wise, I. Walmsley, and C. L. Tang, *Applied Physics Letters*, 52 (7) 519-521 (February 1988).
17. "Electro-Optic Effect in Barium Metaborate," H. Nakatani, W. Bosenberg, K. Cheng, and C. L. Tang, *Applied Physics Letters*, 52, 1288-1290 (April 1988).

18. "Growth and Characterization of Barium Metaborate," L. K. Cheng, W. Bosenberg, and C. L. Tang, *Journal of Crystal Growth* (1988).
19. "Growth and Characterization of Nonlinear Optical Crystals Suitable for Frequency Conversion," L. K. Cheng, W. R. Bosenberg, and C. L. Tang, Invited Review, *Progress in Crystal Growth and Characterization*.
20. "Femtosecond Ultraviolet Pulse Generation in  $\beta$ -BaB<sub>2</sub>O<sub>4</sub>," D. C. Edelstein, E. S. Wachman, L. K. Cheng, W. R. Bosenberg, and C. L. Tang, *Applied Physics Letters*, 52, 2211-2213 (June 27, 1988).
21. "Broadly Tunable Optical Parametric Oscillation in  $\beta$ -BaB<sub>2</sub>O<sub>4</sub>," L. K. Cheng, W. R. Bosenberg, and C. L. Tang, *Applied Physics Letters* (July 1988).
22. "Theory of Quantum Beats in Optical Transmission-Correlation and Pump-Probe Experiments for a General Raman Configuration," I. A. Walmsley, M. Mitsunaga, and C. L. Tang, *Phys. Rev. A*, 4681-4689 (November 1988).
23. "Femtosecond Spectroscopy of Semiconductors and Large Molecules," C. L. Tang, F. Wise, and I. A. Walmsley, Invited, *Journal of Modern Optics*, 35 (December 1988).
24. "Broadly Tunable High Repetition Rate Femtosecond Optical Parametric Oscillator," D. D. Edelstein, E. S. Wachman, and C. L. Tang, *Applied Physics Letters*, 54, 1728-1730 (May 1, 1989); also, Post Deadline paper, CLEO '89, April 27, 1989, Baltimore, MD.
25. "Femtosecond Laser Studies of the Relaxation Dynamics of Semiconductors and Large Molecules," C. L. Tang, F. W. Wise, M. J. Rosker, and I. A. Walmsley, invited review, *IBM Journal of Research and Development*, 33, 447-454 (July 1989).
26. "Subpicosecond Luminescence Study of Hot-Electron Relaxation in GaAs Quantum Wells," F. W. Wise and C. L. Tang, *Sol. State Comm.* 69, 821-826 (1989).
27. "Ultrashort Optical Pulses," invited review, *Encyclopedia of Phys.*, G. L. Trigg, ed. (VCH Publishers, Inc., NY).
28. "Continuous-Wave Mode-Locked and Dispersion-Compensated Femtosecond Optical Parametric Oscillator," E. S. Wachman, D. C. Edelstein, and C. L. Tang, *Optics Letters*, 15, 136-138 (January 15, 1990).

ULTRAFAST STUDIES OF DEVICE STRUCTURES AND OF HOT CARRIERS IN  
NARROW BANDGAP SEMICONDUCTORS

TASK #: 3

TASK PRINCIPAL INVESTIGATOR: C. R. Pollock  
(607) 255-5032

DEGREES AWARDED:

1. Joseph F. Pinto  
Ph.D, 1988  
"Development of a Color Center Laser in NaCl"
2. Christopher P. Yakymyshyn,  
Ph.D, 1989  
"The Additive Pulse Modelocked NaCl Laser"

JSEP PUBLICATIONS:

1. "Additive-Pulse Mode-Locked NaCl:OH- Laser," C. P. Yakymyshyn, J. F. Pinto, and C. R. Pollock, *Optics Letters*, 14, 621-623 (1989).
2. "Frequency Doubled Additive Pulse Modelocked NaCl Laser," C. P. Yakymyshyn, and C. R. Pollock, *Optics Letters*, 14, 791-793 (1989)
3. "Dispersion Effects in Coupled Cavity Lasers," B. J. Zook, C. P. Yakymyshyn, and C. R. Pollock, submitted to *Journal of Opt. Soc. Am. B*, (February 1990).
4. "Optical Adaptive Signal Processing: An Appraisal," R. R. Bitmead, C. R. Johnson, Jr., and C. R. Pollock, submitted to *International Journal of Adaptive Control and Signal Processing*, June 1990.

## PHYSICS OF HIGH SPEED MESO SCALE COMPOUND SEMICONDUCTOR DEVICES

TASK #: 4

TASK PRINCIPAL INVESTIGATOR: J. P. Krusius  
(607) 255-3401

### DEGREES AWARDED:

1. A. Al-Omar  
Ph.D., August 1988  
"Hot Electron Transport in Nanometer Scale Graded Ternary III-V Semiconductor Heterostructures"

### ISEP PUBLICATIONS

1. "Boundary Limited High Field Transport in Ultra Small Devices," A. Al-Omar and J. P. Krusius, *Fundamental Research on the Numerical Modelling of Semiconductor Devices and Processes*. Edited by J. J. H. Miller, Boole Press, Dublin, pp. 3-9, 1987.
2. "Microscopic High Field Transport in Graded Heterostructures," A. Al-Omar and J. P. Krusius, presented at *Fifth International Conference on Hot Carriers in Semiconductors* (July 1987); published in *Solid State Electronics*, 31 (#3/4) 329 (1988).
3. "Space Charge Effects on Heterojunction Cathode (Al:Ga)As Gunn Oscillators," A. Al-Omar, J. P. Krusius, Z. Greenwald, D. Woodard, A. R. Calawa, and L. F. Eastman, *Proceedings of IEEE/Cornell Conference on Advanced Concepts in High Speed Semiconductor Devices and Circuits*, IEEE, New York, 365-372 (1987).
4. "Self-Consistent Monte Carlo Study of High Field Carrier Transport in Graded Heterostructures," A. Al-Omar and J. P. Krusius, *Journal of Applied Physics*, 62 (9) 3825-3835 (November 1987).
5. "Conditions for Space-Charge Reversal at Thermionic Heterojunctions Designed for Ballistic Electron Injection," A. Al-Omar and J. P. Krusius, *IEEE Electron Device Letters*, 9 (2) 81-83 (February 1988).
6. "Hot Electron Transport in Nanometer Scale Graded Ternary III-V Semiconductor Devices," A. Al-Omar, PhD Thesis, Cornell University, Ithaca, NY, 1988, 343 pages.

7. "Conditions for Space Charge Reversal at Thermionic Heterojunctions Designed for Ballistic Electron Injection," A. Al-Omar and J. P. Krusius, *IEEE Electron Device Letters*, 9 (2) 81 (1988).
8. "Investigation of Lateral Effects on Electron Launching in Graded AlGaAs-GaAs Heterostructure Devices Using Two-Dimensional Self-Consistent Monte Carlo Method," S. Weinzierl and J. P. Krusius, presented at the NASECODE VI Conference, Dublin, Ireland, July 11-14, 1989. *Proceedings of the Sixth International NASECODE Conference*, Boole Press, Ireland, edited by J.J.H. Miller, pp. 434-440.
9. "Lateral Space-Charge Effects on Ballistic Electron Transport Across Graded Heterojunctions," S. Weinzierl and J. P. Krusius, presented at the 6th International Conference on Hot Carriers, Phoenix, Arizona, July 1989. *Solid State Electronics*, 32, (#12), 1557-1561 (1989).
10. "Optimization of the Design of the Heterojunction Vertical Field Effect Transistor Using a Two-Dimensional Self-Consistent Monte Carlo Method," S. Weinzierl and J. P. Krusius, presented at the 1989 IEEE/Cornell Conference on High Speed Devices and Circuits, Ithaca, NY, August 1989. *Proceedings of the IEEE/ Cornell Conference on Advanced Concepts in High Speed Semiconductor Devices and Circuits*, IEEE, Cat. No. 89CH2790-4, pp. 237-245 (1989).
11. "Simulation of Ultrafast Carrier Processes in Pulse/Probe and Dual Pulse Correlation Probing of InGaAs Type Narrow Gap Semiconductors," J. E. Bair and J. P. Krusius, presented at the SPIE Technical Conference on Advances in Semiconductors and Superconductors: Physics Toward Device Applications: Ultrafast Laser Probe Phenomena in Bulk and Microstructure Semiconductors III, Conference 1282, San Diego, March 17-21, 1990 (invited paper); accepted for publication in proceedings, April 1990 (in press).
12. "Conditions for Suppression of Ballistic Injection at AlGaAs/GaAs Heterojunctions due to Lateral Space Charges," S. Weinzierl and J. P. Krusius, manuscript submitted for publication to *IEEE Electron Device Letters*, (March 1990).
13. "Physics of High Frequency Operation of Vertical Field Effect Devices with Ballistic Launchers," S. Weinzierl and J. P. Krusius, manuscript in progress, to be submitted for publication (September 1990).
14. "Femtosecond Relaxation Dynamics of Electrons and Holes in  $\text{In}_x\text{Ga}_{1-x}\text{As}$  Thin Films for Near Band Gap Excitation," J. Bair and J. P. Krusius, manuscript in progress, to be submitted for publication (September 1990).

## NOVEL VLSI ALGORITHMS AND ARCHITECTURES FOR HIGH DATA RATE DIGITAL FILTERING

TASK #: 5

TASK PRINCIPAL INVESTIGATOR: Gianfranco Bilardi  
(607) 255-9212

### DEGREES AWARDED:

1. Kieran Herley  
Ph.D., Computer Science, December 1989  
"Deterministic Simulation of Shared Memory on Bounded Degree Networks"

### ISEP PUBLICATIONS:

1. "Area vs. Time: A Tradeoff in a VLSI Computer," G. Bilardi, *Engineering Cornell Quarterly*, 23 (1) 26-30, Autumn 1988.
2. "Deterministic Simulations of PRAMs on Bounded-Degree Networks," K. Herley and G. Bilardi, *Proceedings of the 26th Annual Allerton Conference on Communication, Control, and Computing*, 1084-1093, Monticello, Illinois, September 1988. An extended version appears in the Technical Report 88-951, Department of Computer Science, Cornell University, November 1988.
3. "Optimal VLSI Architectures for Multidimensional DFT," G. Bilardi, S. Hornick, and M. Sarrafzadeh, *1989 ACM Symposium on Parallel Algorithms and Architectures*, 265-272, Santa Fe, New Mexico, June 1989.
4. "Time Lower Bounds for CREW-PRAM Computation of Monotone Functions," G. Bilardi and A. Moitra, *International Symposium on Automata, Languages, and Programming*, Stresa, Italy, 95-107, July 1989. Also Technical Report 89-1012, Department of Computer Science, Cornell University, May 1989.
5. "Efficient Simulations of Small Shared Memories on Bounded Degree Networks," K. Herley, *Proceedings of the 30th Annual Symposium on Foundations of Computer Science*, 390-395, North Carolina, October 1989.
6. "Improved Bounds for the Token Distribution Problem," K. Herley, Technical Report 89-1051, Department of Computer Science, Cornell University, October 1989.

7. "Deterministic Simulation of Shared Memory on Bounded-Degree Networks," K. Herley, Ph.D. Thesis, Technical Report 90-1090, Department of Computer Science, Cornell University, February 1990.
8. "Characterization of Associative Operations with Prefix Circuits of Constant Depth and Linear Size," G. Bilardi and F. P. Preparata, *SIAM Journal on Computing*, 19, (2) April 1990.
9. "Deterministic On-line Routing on Area-Universal Networks," P. Bay and G. Bilardi, to be presented at 1990 IEEE Symposium on the Foundation of Computer Science, October 1990.

## FAULT TOLERANT SIGNAL PROCESSING ARCHITECTURES

TASK #: 6

TASK PRINCIPAL INVESTIGATOR: Franklin T. Luk  
(607) 255-5075

### DEGREES AWARDED:

1. Joseph Cavallaro  
Ph.D., 1988  
"VLSI Cordic Processor Architectures for the Singular Value Decomposition"
2. L. Magnus Ewerbring  
Ph.D., August 1989  
"A New Generalization of the Singular Value Decomposition: Algorithms and Applications"
3. Cynthia J. Anfinson  
M.S., August 1989  
"A Theory of Algorithm-based Fault Tolerance"
4. David E. Schimmel  
Ph.D., August 1990  
"Bit-Level Jacobi-Like Algorithms for Eigenvalue and Singular Value Decompositions"

### ISEP PUBLICATIONS:

1. F. T. Luk, Editor, *Proceedings of SPIE Vol. 975, Advanced Algorithms and Architectures for Signal Processing III*, SPIE - The International Society for Optical Engineering, Bellingham, Washington, 1988.
2. "A Theoretical Foundation for the Weighted Checksum Scheme," C. J. Anfinson, R. P. Brent, and F. T. Luk, *Proceedings of SPIE Vol. 975, Advanced Algorithms and Architectures for Signal Processing III*, 10-18 (1988).
3. "A Novel Fault Tolerance Technique for Recursive Least Squares Minimization," C. J. Anfinson, F. T. Luk, and E. K. Tornø, *Proceedings of SPIE Vol. 975, Advanced Algorithms and Architectures for Signal Processing III*, 268-276 (1988).
4. "VLSI Arrays for Signal Processing," F. T. Luk and D. E. Schimmel, *Cornell Engineering Quarterly*, 23, (1), 15-17 (Autumn 1988).

5. "Checksum Schemes for Fault Tolerant Systolic Computing," R. P. Brent, F. T. Luk, and C. J. Anfinson, Paper presented at Conference on Mathematics in Signal Processing, Warwick, England (December 1988). Proceedings will appear in 1989.
6. "Computing Generalized Canonical Correlations," L. M. Ewerbring and F. T. Luk, Paper presented at NATO Advanced Study Institute on Numerical Linear Algebra, Digital Signal Processing and Parallel Algorithms, Leuven, Belgium (August 1988). Proceedings will appear in 1989.
7. *Proceedings of SPIE Vol. 1152, Advanced Algorithms and Architectures for Signal Processing IV*, F. T. Luk, Editor, SPIE - The International Society for Optical Engineering, Bellingham, Washington, 1989, 43 papers/507 pages.
8. "A Novel Fault Tolerance Technique for Recursive Least Squares Minimization," F. T. Luk, E. K. Torng, and C. J. Anfinson, *Journal of VLSI Signal Processing*, 1, 181-188 (1989).
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## REAL-TIME SIGNAL PROCESSING SYSTEMS WITH MULTIPLE FUNCTIONAL UNITS

TASK #: 7

TASK PRINCIPAL INVESTIGATOR: H. C. Torng  
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### DEGREES AWARDED:

1. Martin F. R. Day  
Master of Engineering, May 1989
2. George E. Daddis, Jr.  
Ph.D., May 1990  
"Studies in Superscalar Processors and Communication Networks"

### ISEP PUBLICATIONS:

1. "Instruction Issuing Mechanism for Processors with Multiple Functional Units," H. C. Torng, U. S. Patent 4,807,115 (February 21, 1989).
2. "A Fast Instruction Dispatch Unit for Multiple and Out-of-Sequence Issuances," H. Dwyer and H. C. Torng, Technical Report EE-CEG-88-09 (July 1988).
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4. "A New Interrupt Handling Approach for Out-of-Order Execution Machines," Martin Day and H. C. Torng, submitted to Fourth International Conference on Architectural Support for Programming Languages and Operating Systems.
5. "The Concurrent Execution of Multiple Instruction Streams on Superscalar Processors," George E. Daddis Jr. and H. C. Torng, manuscript in preparation.
6. "A Data Flow Dispatch Stack," G. E. Daddis, Jr. and H. C. Torng, manuscript in preparation. To be submitted to *IEEE Transactions on Computers*, September 1990.

7. "Branch Prediction in the Dispatch Stack," G. E. Daddis, Jr.. and H. C. Tornig, manuscript in preparation.